Dynamics of Hot Plasma

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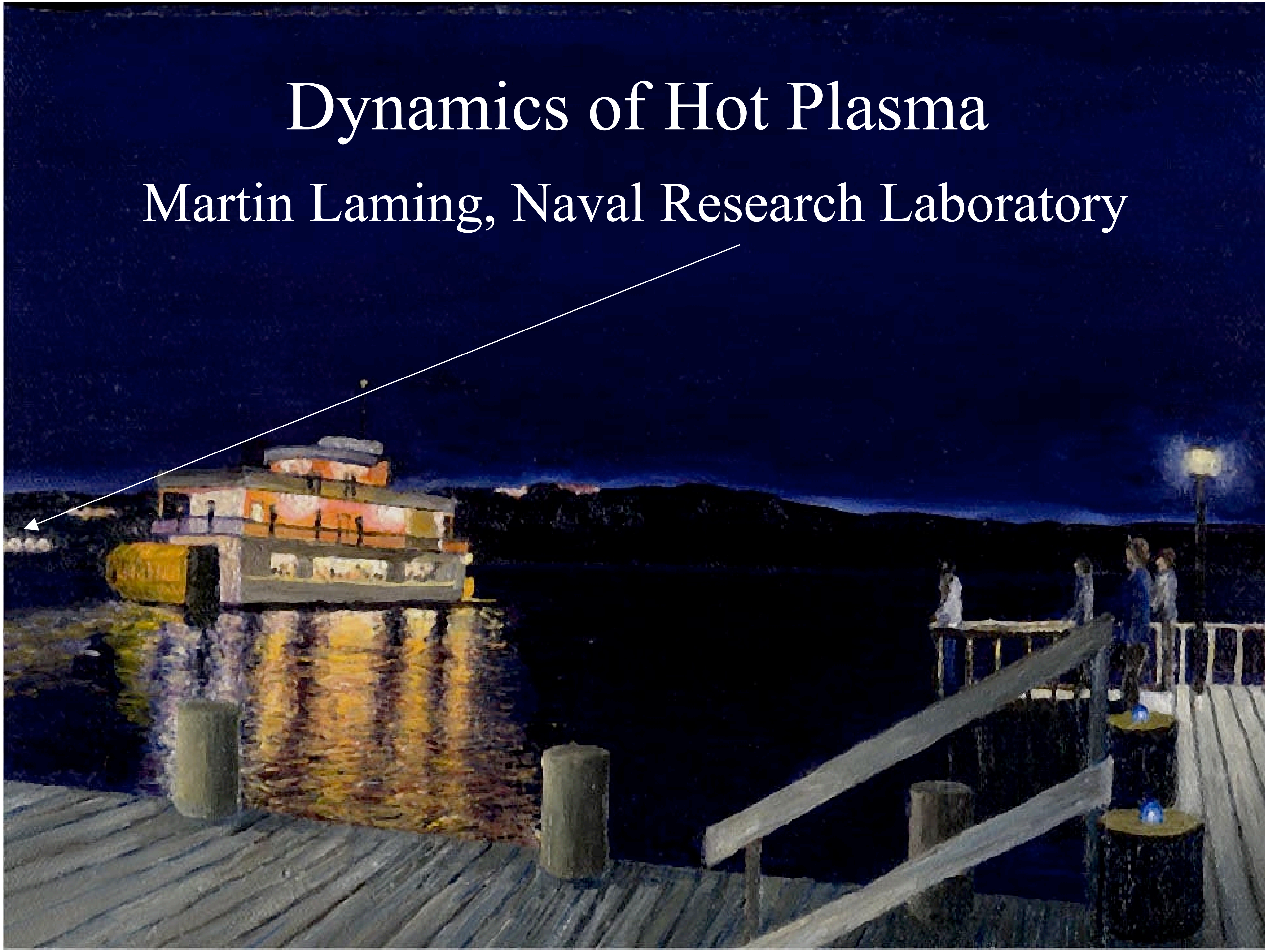


Dynamical Studies of Hot Plasmas

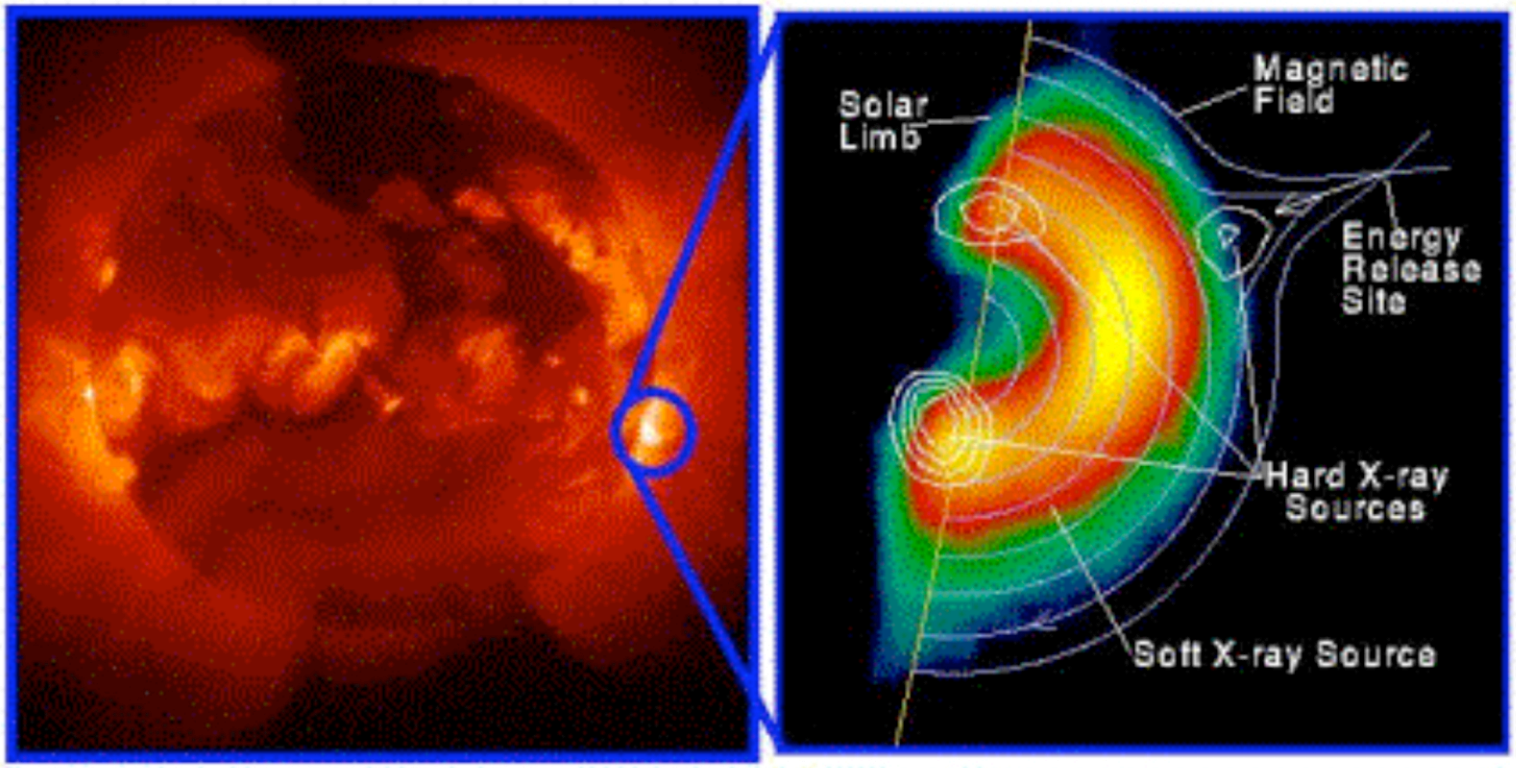
including AGN outflows, cooling flows, etc.

- Dynamics in coronal loops
- Stellar flares, optical, x-ray, hard emission and SED vs time
- Doppler imaging of stars/stellar flares
- SNR shocks
- Clusters: turbulence, shocks, cold fronts, mergers
- Non equilibrium ionization

Stellar Coronae/Flares: Big Picture

- Frequently missing (or vague) in papers and proposals!
- Low β plasma (magnetic energy >> thermal energy), BUT turbulent energy density ~ thermal energy ◊ plasma strongly influenced by MHD wave-particle interactions.
- Expect fundamental insights into MHD processes such as particle acceleration & heating, thermal conduction.
- Never forget: The most important stellar corona of them all is that on the Sun!

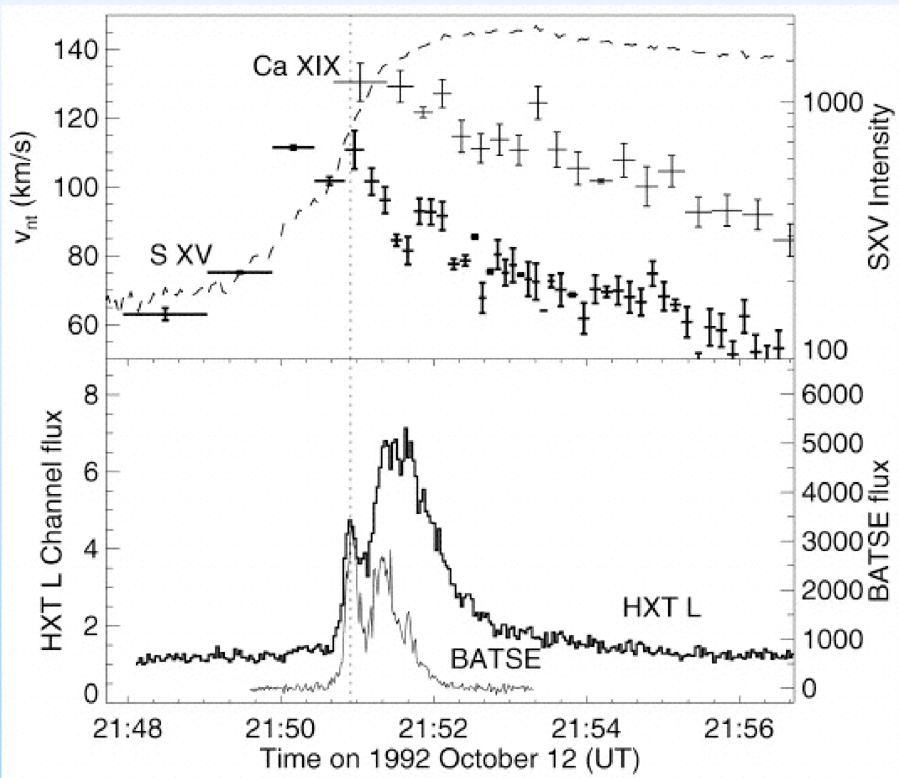
Anatomy of a Flare

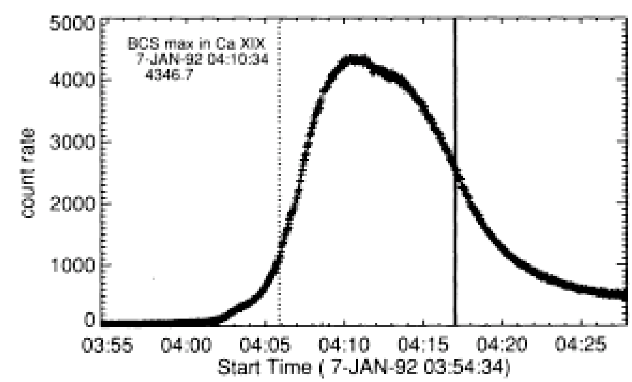


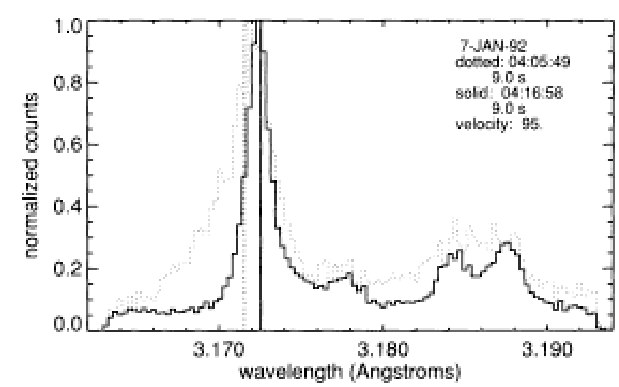
Yohkoh X-ray Image of a Solar Flare, Combined Image in Soft X-rays (left) and Soft X-rays with Hard X-ray Contours (right). Jan 13, 1992.

Soft X-rays vs. hard, & blueshifts

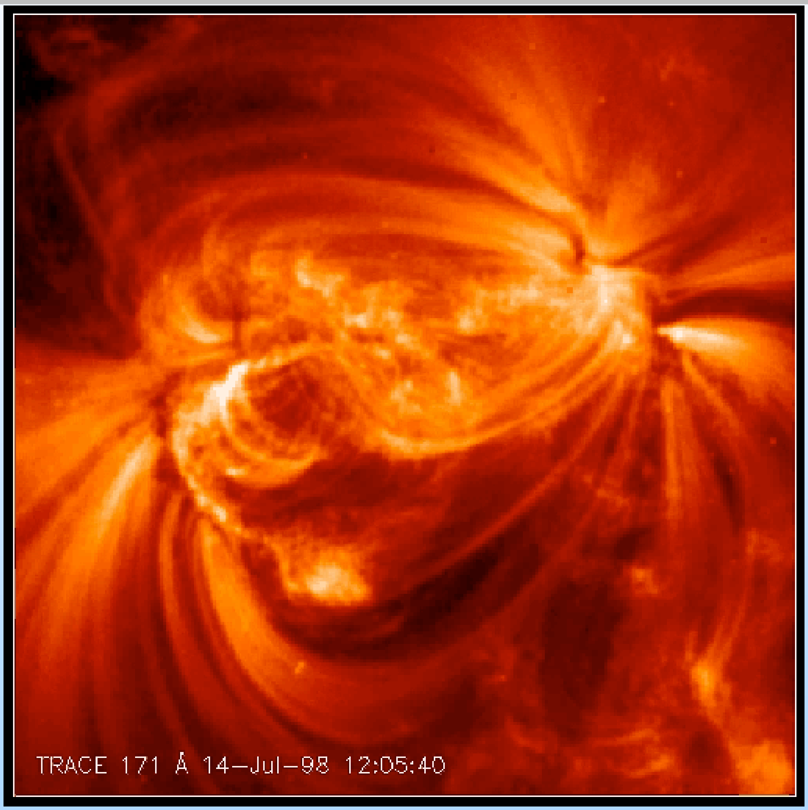
(from Alexander et al. 1998, ApJ, 494, L235, and Mariska et al. 1993, ApJ, 419, 418)

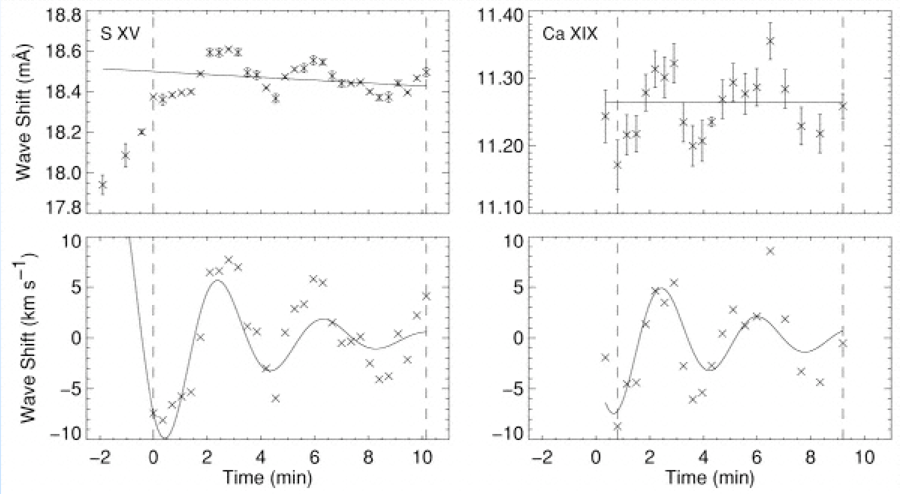






Solar Flare Loop Oscillations





YOHKOH/BCS Spectroscopy
10/12/92
(Mariska 2005, ApJ, 620, L67)

Imaging by TRACE, 7/14/98

Similar to Con-X obs. of 1.e34-35 erg event on AD Leo or EV Lac?

AT Mic Flare Intensity Variation

Mitra-Kraev & Harra (2004) astro-ph/0410656

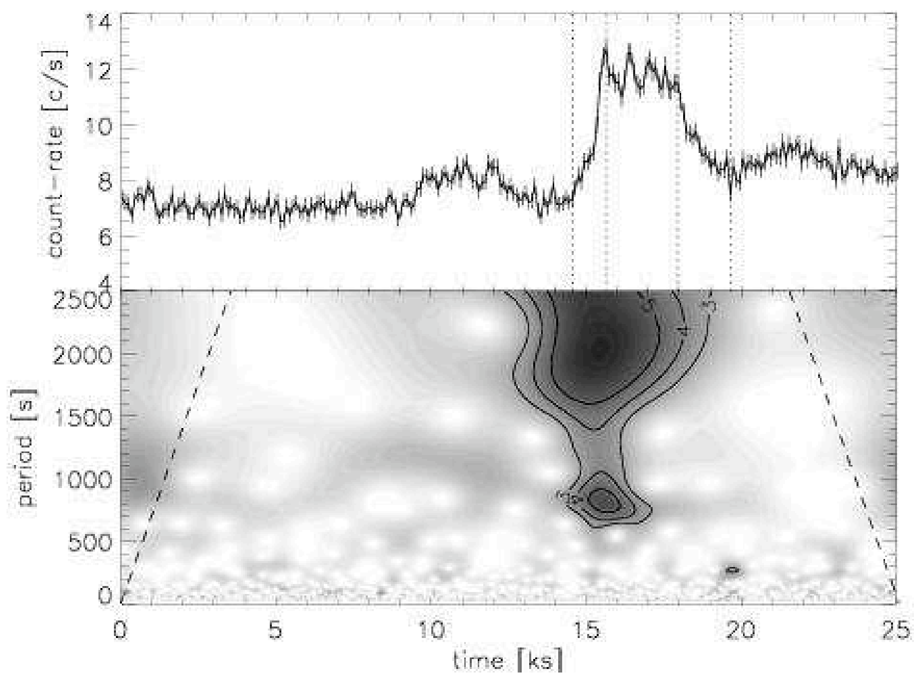


Figure 1. The light curve and wavelet coefficients of AT Mic. The observation started on 2000-10-16 at 00:42:00 h and lasted for 25'100 s (~ 7 h). The upper panel shows the observed light curve, binned up to 100 s. The vertical dashed lines indicate the start and end of the rise and decay phase of the flare. The lower panel shows the absolute values of a section of the corresponding wavelet coefficients (see main text) divided by their standard deviation. The 3, 4 and 5 σ significance contour lines are drawn. The two dashed lines mark the border of the cone of influence. A local maximum is clearly seen with a period of around 740 s during the flare peak.

XMM-Newton/EPIC obs.

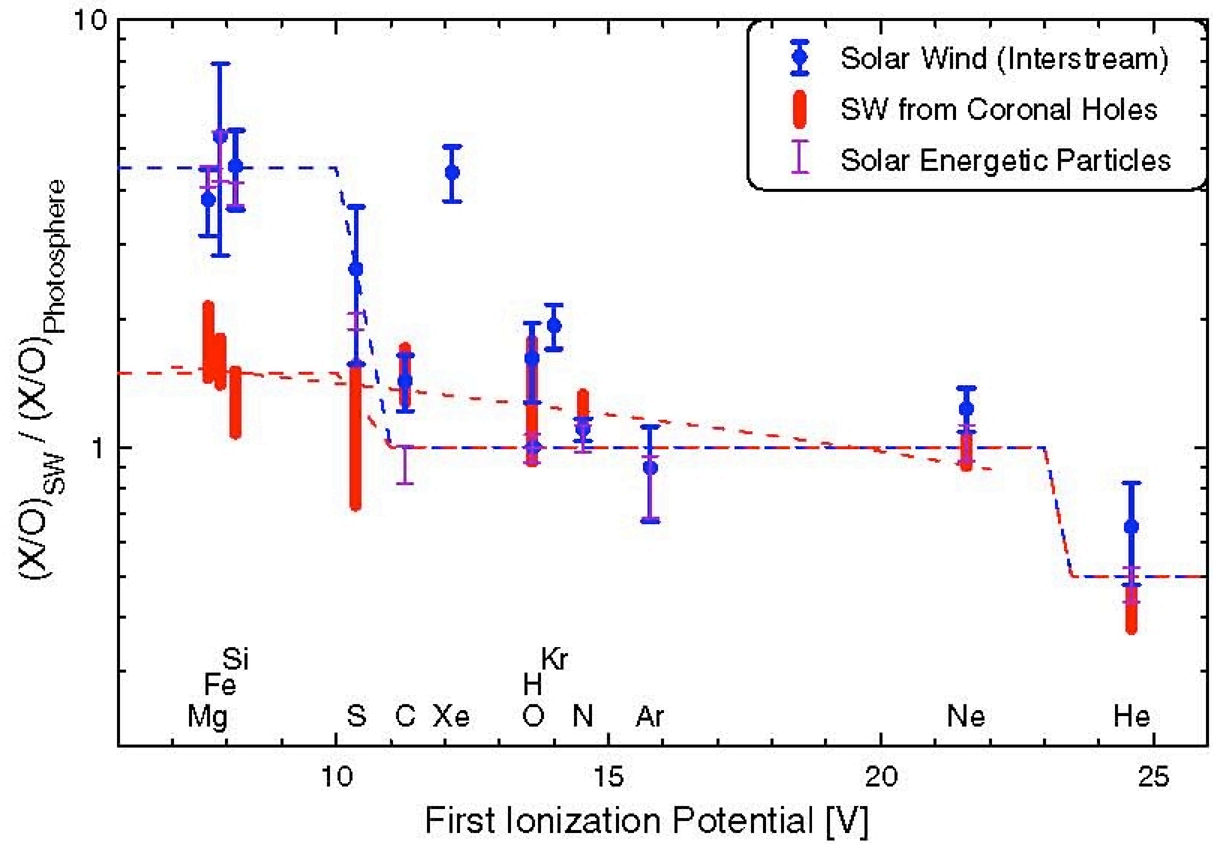
Probably NOT a simple acoustic wave; decays too slowly.

Need Doppler shifts and intensities π/2 out of phase for conclusive ID.

See **http://www.astro.warwick.ac.uk/~valery/** (Valery Nakariakov's web site at Warwick University) for lots more info.

Coronal Abundances are Different!

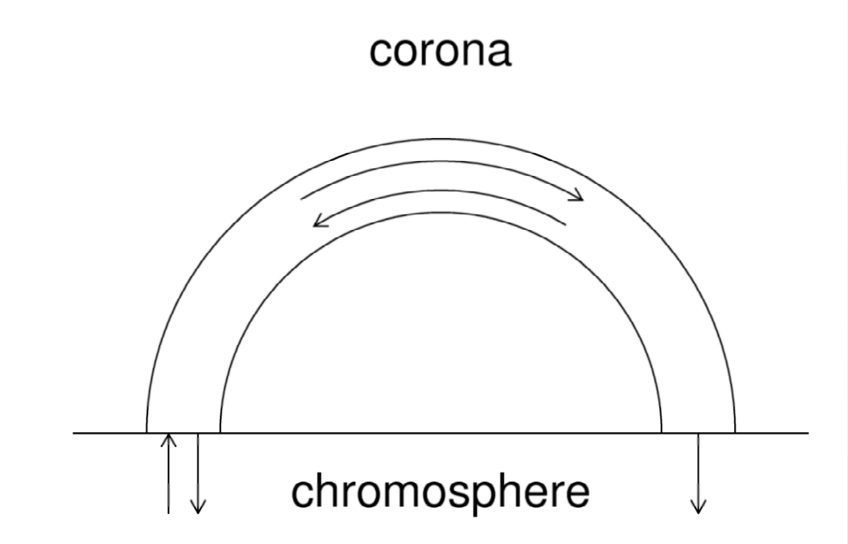
(Coronal abundance enhancement of elements with FIP < ~10 eV)



FIP/Inverse FIP Effect Model

(from Laming, J. M. 2004, ApJ, 614, 1063)

- Coronal loop acts as resonant cavity to Alfven waves coming up from solar convection zone.
- Standing wave pattern established by loop resonant properties and wave refraction in density gradients gives (ponderomotive) forces on charged particles.



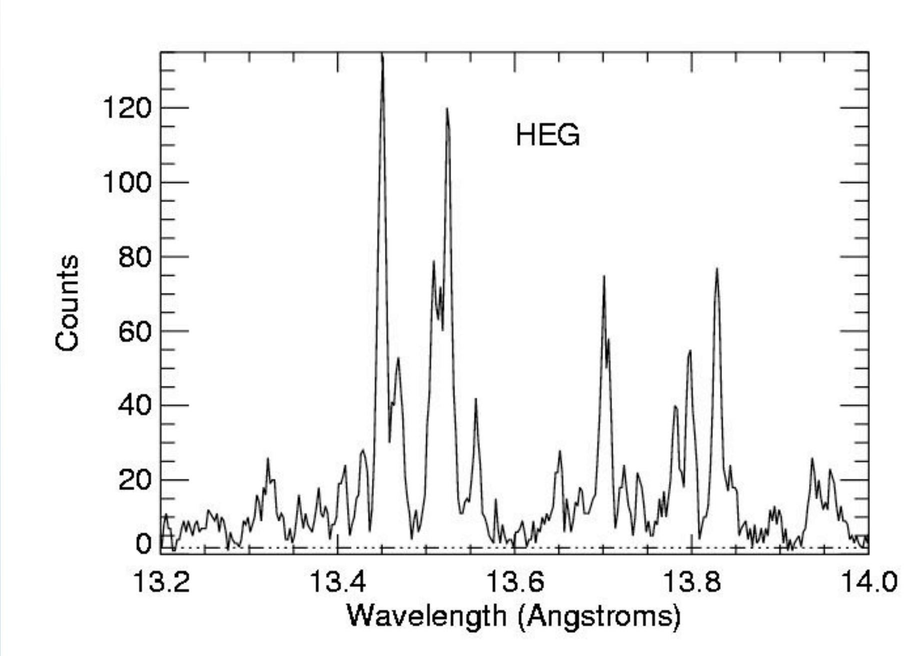
Strong wave transmission ◊ upwards force ◊ FIP Effect
Strong wave reflection ◊ downwards force ◊ Inverse FIP Effect

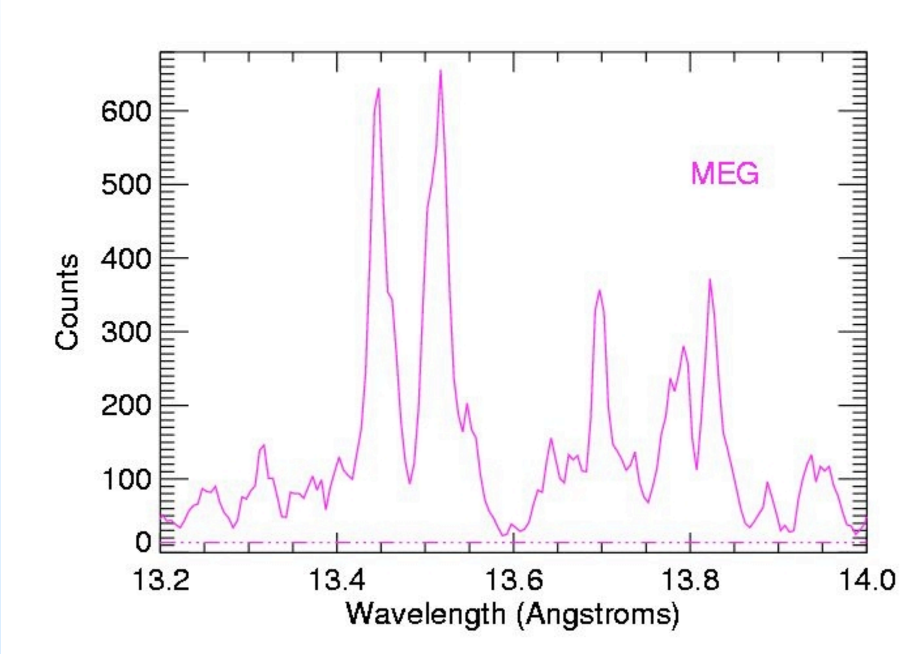
The Things we Want to See

- Chromospheric evaporation (blueshifts), predicted @ 1000 km/s (seen on Sun more typically with 200 km/s) ◊ $E/\delta E \sim 1500$; 4 eV @ 6 keV.
- Chromospheric evaporation (abundance changes), need similar resolution at longer wavelength, i.e. grating resolution $E/\delta E \sim 1500$ @ 1 keV.
- Hard x-rays, timing w.r.t. soft x-ray emission, ok with 1500 cm^2 for closest flare stars (~5pc).
- Loop oscillations, period few minutes, amplitude few km/s or higher; ok with calorimeter resolution, but needs high throughput, my estimates assumed 3 m^2.
- Doppler imaging, ok with grating resolution above, but needs high throughput.

Capella at Different Resolutions

(thanks to Nancy Brickhouse)

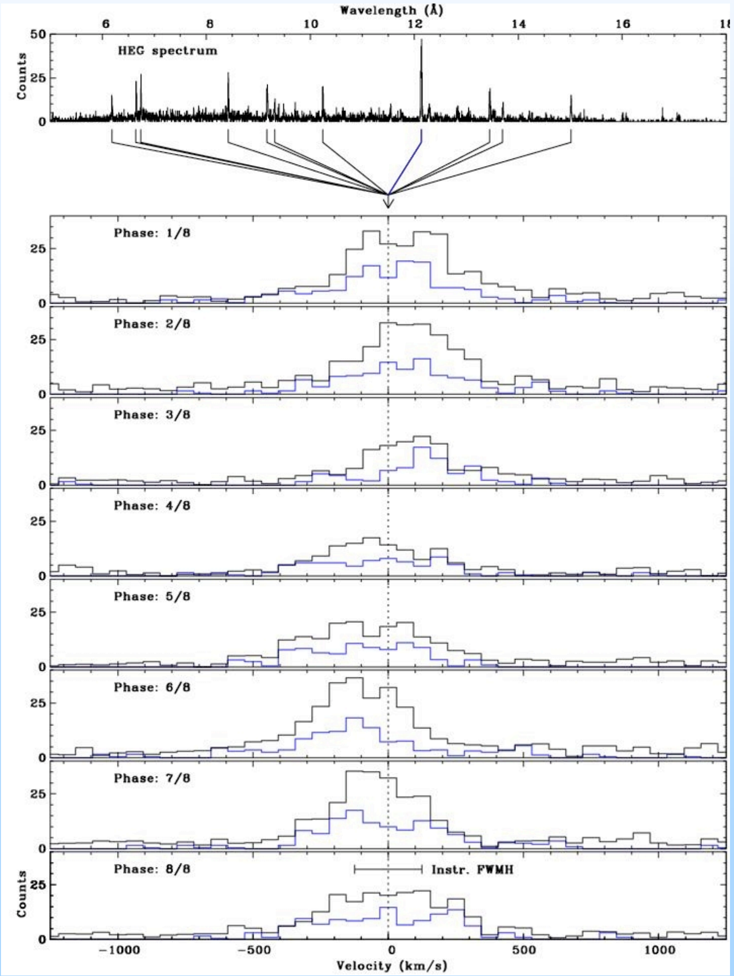


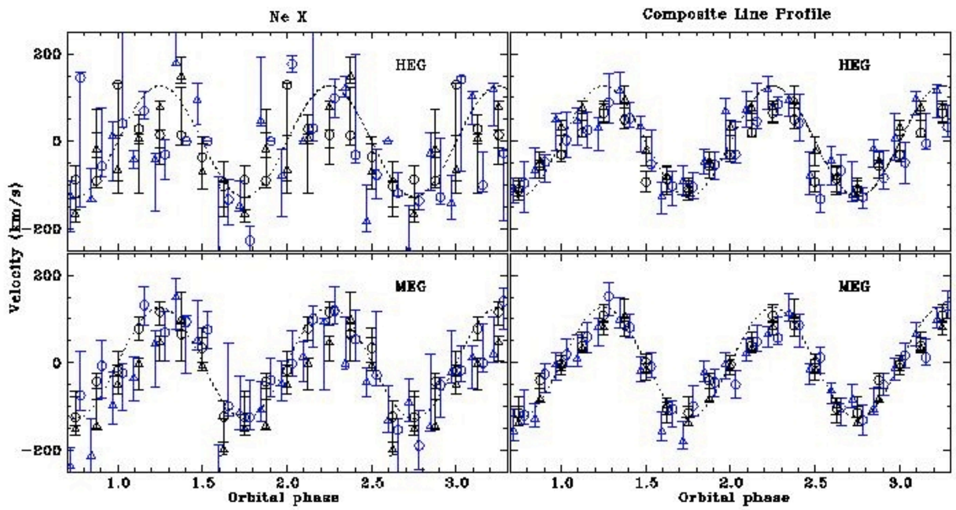


Congested Ne IX/Fe XIX region, how do we find flare blueshifted emission here?

Doppler Imaging of 44 Boo

(thanks to Nancy again)

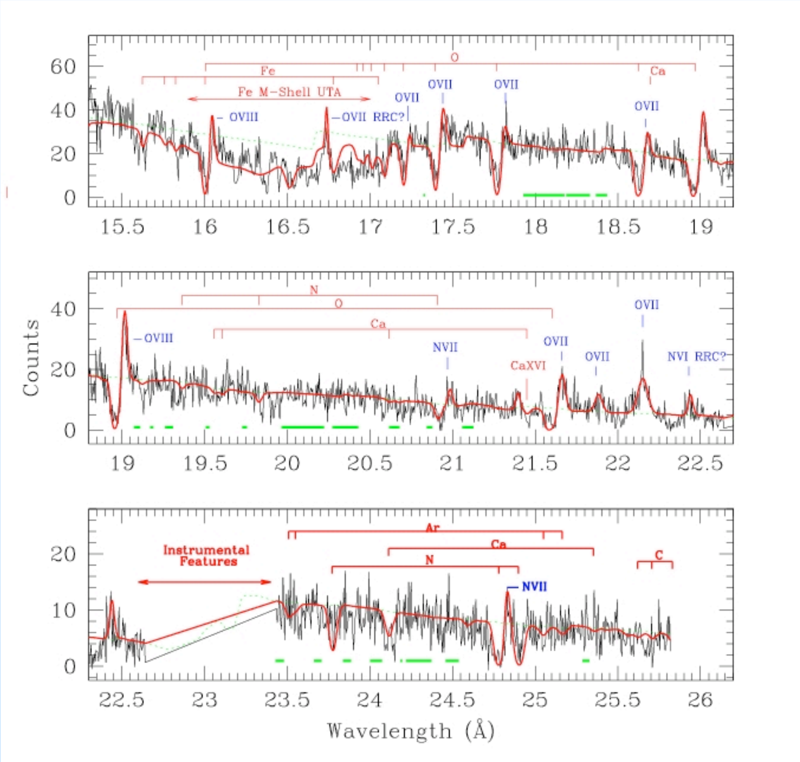


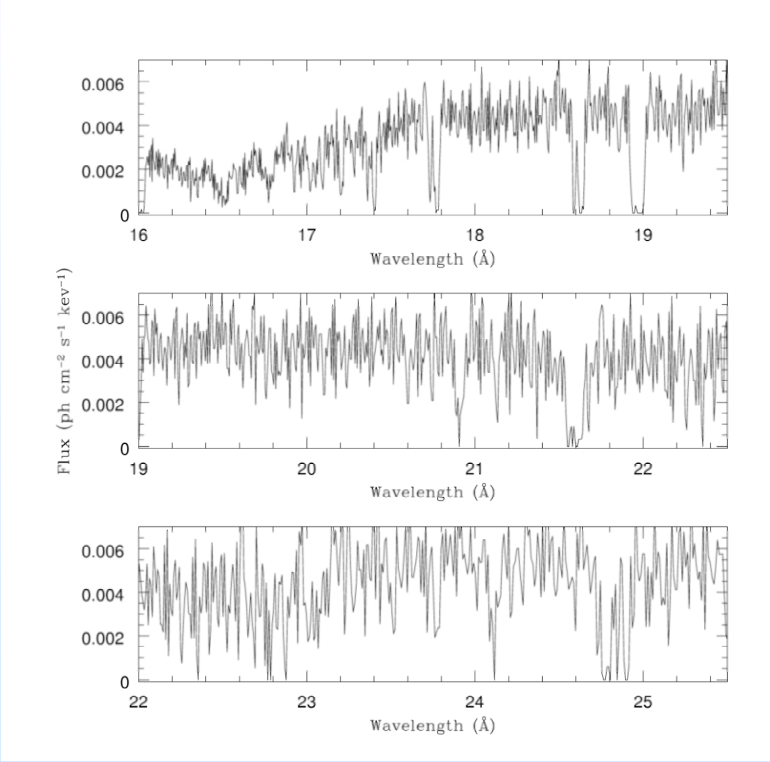


Around a dozen cool star candidates for this type of work, also CV's

NGC 3783 Warm Absorber

(thanks to Yair Krongold-Herrera)



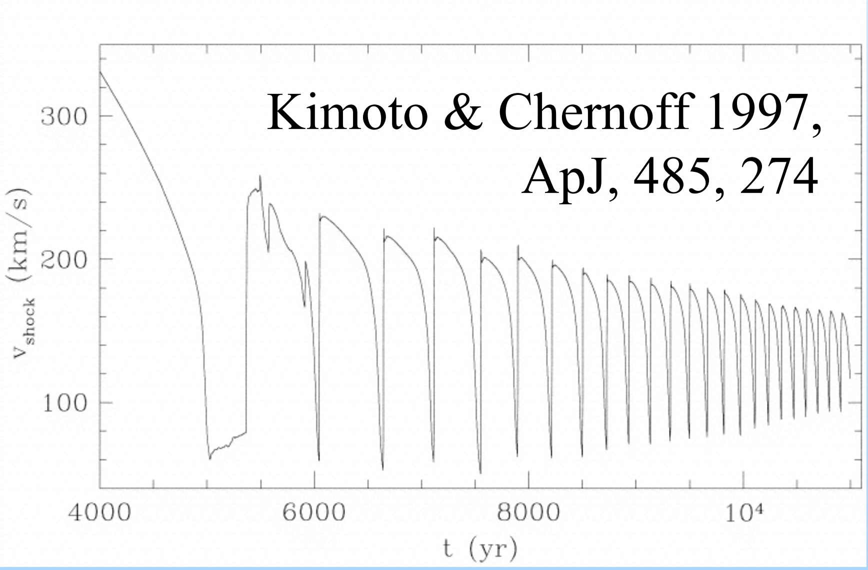


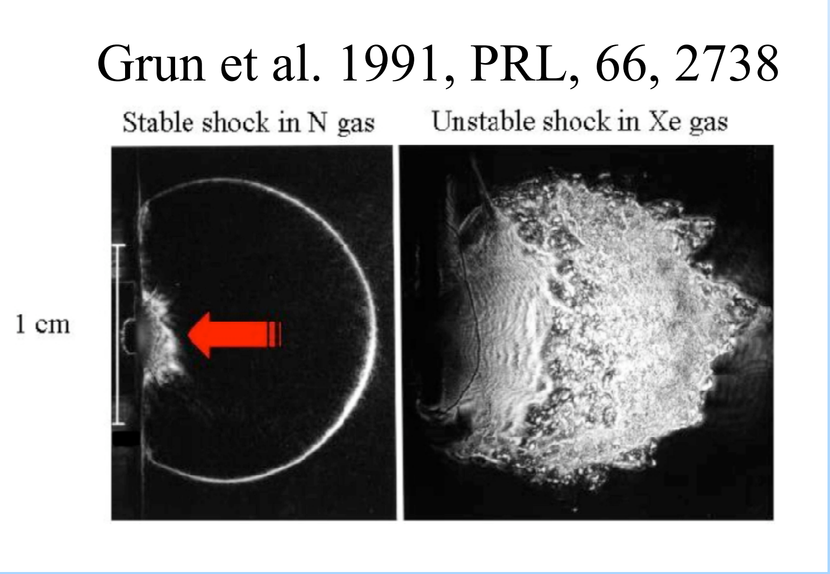
900 ks MEG, resolution ~ 600 simulation with resolution ~ 3000

Stellar Shock Physics

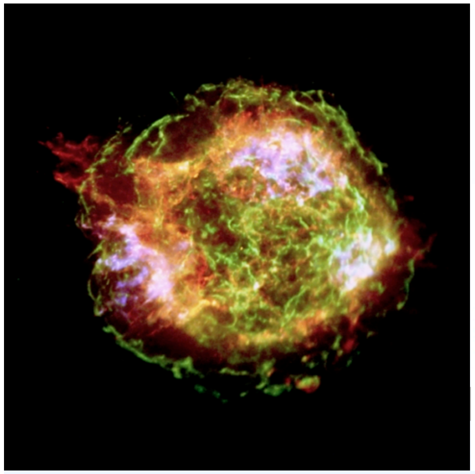
- Accretion shock oscillations on T Tauri stars (e.g. TW Hya)
- Radiative shock oscillations in stellar winds (e.g. ζ Pup)

Periods typically a few secs (radiative cooling time), look for QPO in strong lines with count rates 1-10 sec^{-1} (assuming $3m^2$ area).

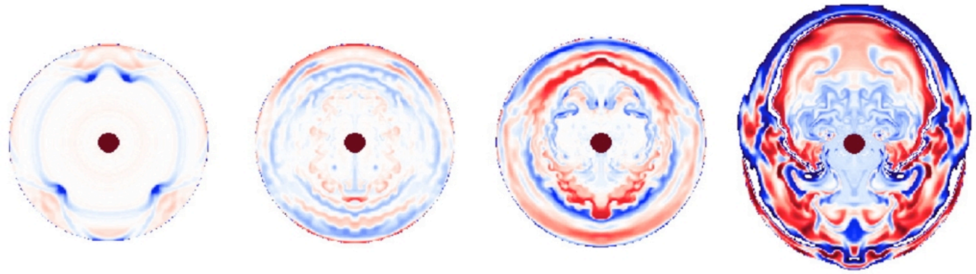




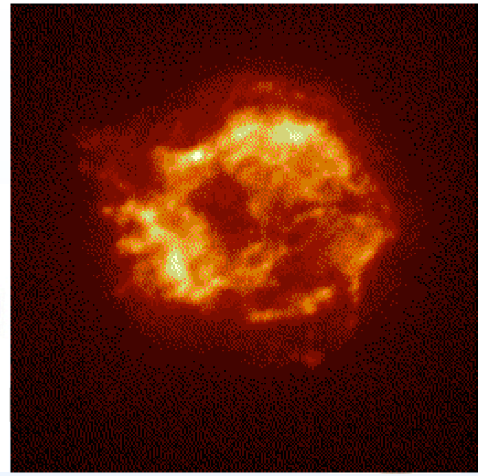
SNR Shock Physics



Hwang et al 2004, ApJ, 615, L117



Blondin et al. 2003, ApJ, 584, 971

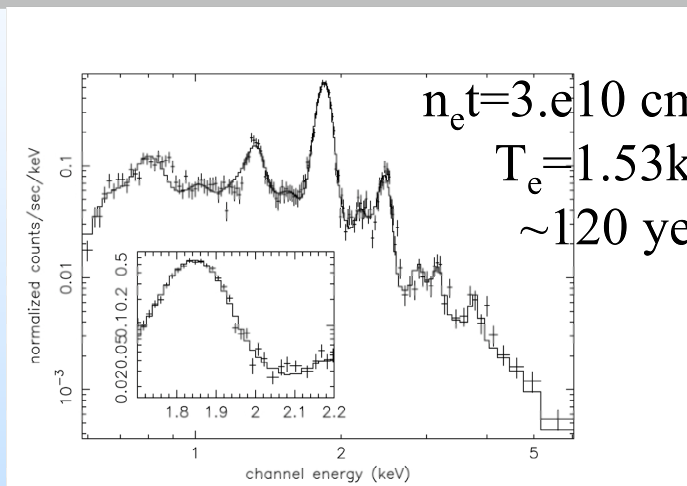


Vink et al. 1996, A&A, 339, 201

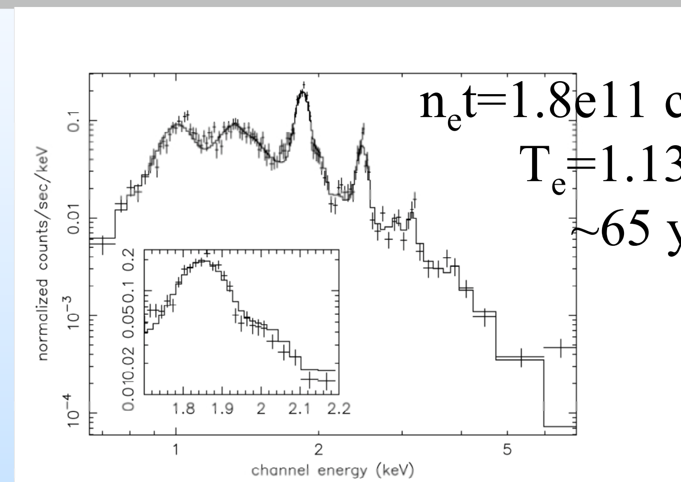
- Measurements of shock velocities unlikely from proper motions (needs subarcsecond resolution for significant improvement).
- Calorimeter/grating resolution will allow accurate line profiles, which combined with shock velocities give some handle on T_e/T_i, but probably needs spatial resolution < 5” (2” is better, 15” is probably no good).
- Combine with ionization nonequilibrium modeling (see next slide) for firmer understanding.

Ionization Non-equilibrium in Cas A

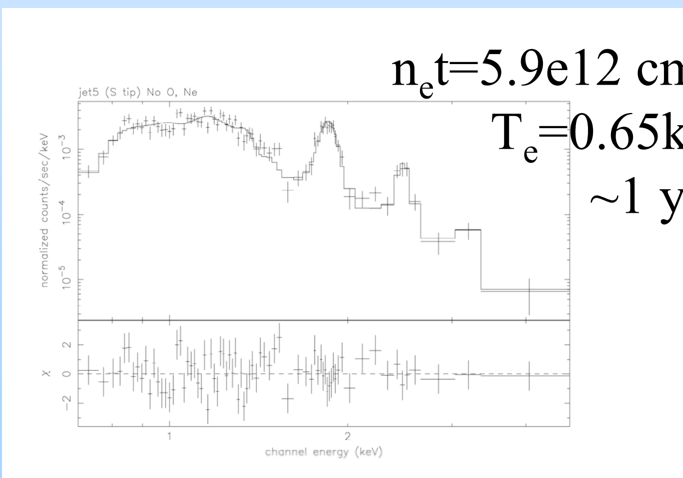
notice how Si XIII/XIV and Fe L spectrum change with $n_e t$



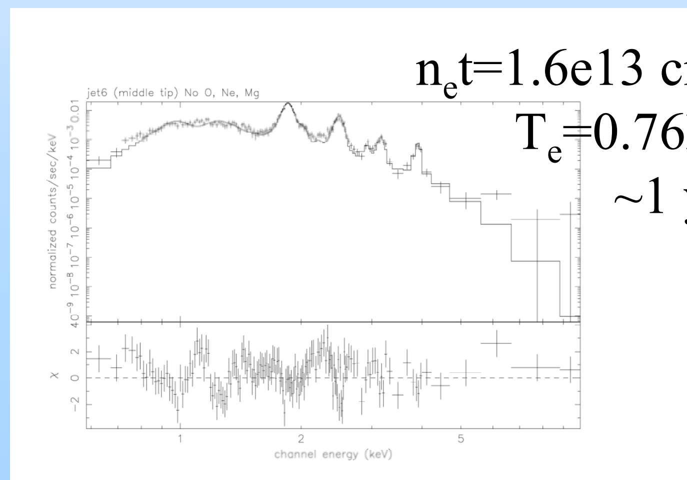
$n_e t$=3.e10 cm^{-3}s
T_e=1.53keV
~120 years



$n_e t$=1.8e11 cm^{-3}s
T_e=1.13keV
~65 years



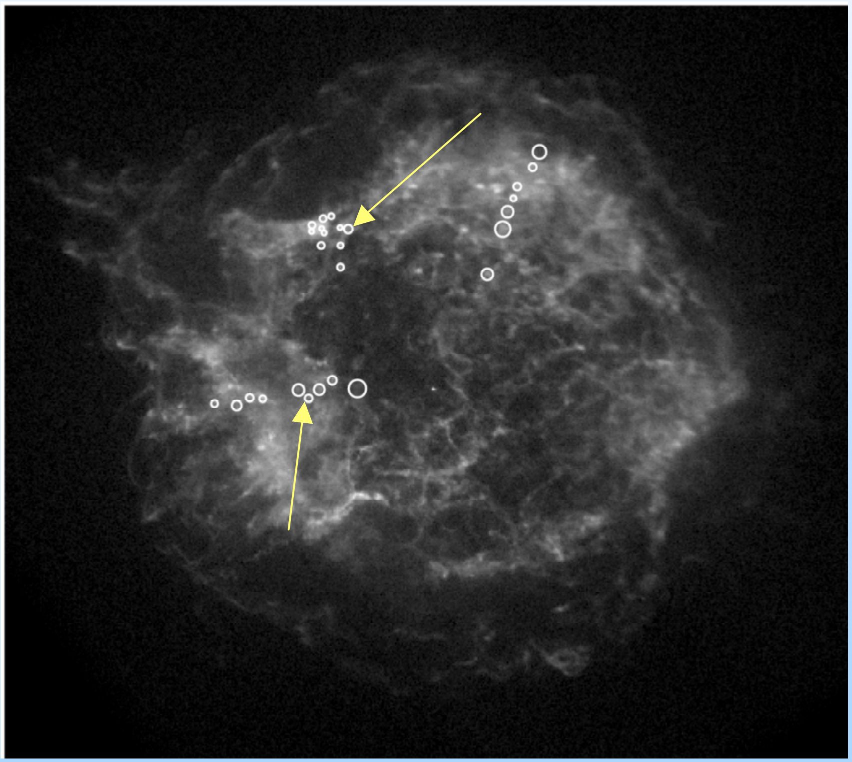
$n_e t$=5.9e12 cm^{-3}s
T_e=0.65keV
~1 year



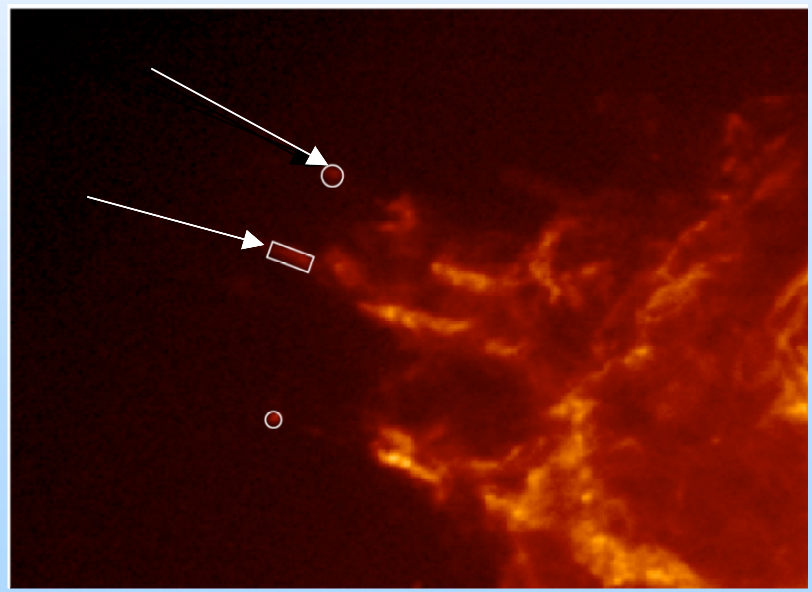
$n_e t$=1.6e13 cm^{-3}s
T_e=0.76keV
~1 year

Isolate emission from ejecta “knots”, measure T_e and $n_e t$

50 ksec Chandra



1 Msec Chandra



Basic Requirements

- Calorimeter resolution 2000 – loop oscillations, blueshifts and chromospheric evaporation
- Grating resolution 2000 – abundances in blueshifted flare emission, Doppler imaging, general spectroscopic diagnostics for emission and absorption lines
- Spatial resolution – 5" for SNRs and stellar clusters
- ***High throughput is the most important requirement***, $3m^2$ assumed herein, higher throughput offers greater scientific return than higher resolutions.
- Hard x-ray coverage out to 100 keV

^{44}Ti Detections in Cassiopeia A

Iyudin et al. (1997; Comptel) 3.3+/- 0.6 e-5 cts/cm^2/s

Vink et al. (2001; BeppoSAX) 1.9+/-0.9 e-5 cts/cm^2/s